NOVEL TAMPER-INDICATING PROTECTIVE METHODS*

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ABSTRACT

Several novel tamper-indicating methods, originally developed under DOE auspices for arms control applications, might be useful in nonproliferation. Some devices that have reached the laboratory prototype stage could provide specialized alternatives to established seals. As locks and cables, the following might be useful: (1) a brittle ceramic lock—impervious to toxic, radiation, and thermal extremes—interrogated for identification and continuity by ultrasonic means, (2) a flexible ceramic-fiber seal that also tolerates severe environments, (3) an ultrasonic smart-material strip seal, and (4) an RF-resonant coaxial cable, verified by radio frequency and microwave signals. To validate the identity of secured surfaces, joints, welds, and fasteners—two techniques are applicable: (1) the scanning electron microscope, which examines three-dimensional micron-level topography, and (2) the plastic-casting fingerprint, a simple low-cost technique, analogous to human fingerprinting. Inert-gas tagging of storage containers and facilities could also be useful for nuclear-warhead components. The techniques mentioned above have one or more of the potential advantages of low cost, immediate availability, security for large-area enclosures, application to hazardous environments, usability in the FSU, or suitability for covert use.

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INTRODUCTION

Tamper-indicating seals and unique-identifier tags have been developed to increase security of sensitive items. Along with other national laboratories, Argonne has participated in DOE programs for R&D of novel tamper-indicating devices (TIDs) and systems to meet specific arms control, nonproliferation, and security purposes.[1]

Eight years ago, DOE organized national laboratories to collaborate in providing technical advice, exchanging information, and carrying out vulnerability analyses on tags and seals. When this program was active, DOE and DOD sponsored a full range of activities leading to field demonstration in some cases.[2] During the Cold War, it was frequently assumed that the Soviets had sophisticated capabilities to evade compliance in arms control treaties. Although that potential was a driving function for most of the TIDs that were developed, some are adaptable to contemporary worldwide security issues. Tags and seals that might have been perceived susceptible to USSR tampering are now suitable for nonproliferation roles.

As a result, it is useful to re-evaluate previously developed TIDs with contemporary standards in mind, such as simplicity, low cost, and compatibility with specialized applications. Although reported here is primarily Argonne R&D, other national laboratories and organizations have TIDs that meet current requirements.

TAMPER-INDICATING-DEVICE R&D

About a dozen TIDs have been initiated at Argonne, mostly based on the need to meet an unfilled requirement at relatively low cost or to satisfy a specialized application when established TIDs were not well suited. A few of these were previously described in terms of application to nuclear-warhead monitoring.[3]

Ceramic Seals

In severe environments—high temperature, toxicity, radiation, etc.—ordinary TIDs might not survive for long periods of time. Ceramics, however, are generally impervious to such extremes. On this basis, an all-ceramic lock and a ceramic-fiber seal have been developed to the prototype stage. Application was envisioned to hazardous chemical facilities monitored under the Chemical Weapons Convention.

Ceramic Lock. A "U"-shaped ceramic connecting element was attached by cold-shrink fit to a ceramic plate or block binding element. A digitized image can be made of the amplitude of the scattered ultrasonic wave scanned as a function of position, thereby providing a unique signature. Because of brittleness, ceramics are inherently resistant to tampering. Any attempt to cut and rebond the ceramic body or joint would leave a characteristic change in ultrasonic transmission. A prototype, made of zirconia, was developed and patented.[4]

Ceramic-Fiber Seal. Ordinarily ceramics are solid and inflexible. However, flexible ceramic fibers have been developed and are commercially available. Silicon carbide fibers are tolerant of environmental extremes and cannot be welded together after fracturing. A prototype cable that is authenticated by ultrasonic transmission has been developed.[5]

Ultrasonic Smart Materials

State-of-the-art developments in embedding ultrasonic sensing and microprocessing elements in materials have been adapted to prototypes for a cable seal and a blanket seal. Tampering with any portion of the cable or blanket would result in an indication that is stored in memory or remotely monitored.

Ultrasonic Cable Seal. Tamper-indication can be obtained from ultrasonic sensors embedded in a cable strip. Built-in memory and control could be included to keep a record of perturbations. A functioning laboratory prototype has been developed.

Ultrasonic Blanket Seal. Smart-material technology has been extended to a seal that can be wrapped around a container. Ultrasonic signals continuously interrogate for penetrations throughout the blanket. A functioning prototype was also developed for this seal.

Radiofrequency (RF) Seals

Commercial anti-theft technology using RF-resonant signals is the basis for a coaxial cable seal that has been tested and for a possible blanket-type seal. Pulses with wavelengths into the microwave region are generated into the cable, and characteristic resonances are measured from reflection or transmission.

RF Cable Seal. In some applications, commercial-grade coaxial or triaxial cables have some advantages over the more common fiber-optic cable seals. They are generally less expensive, widely available, durable, and reliably connected. A semi-rigid cable has been tested successfully, showing its sensitivity to tampering by attempts to restore its original shape. Resistance to tampering at the cable connections might be better for RF than for optical transmission.

RF Blanket Seal. Tamper-resistant seals that enclose large objects are difficult to implement. Argonne had been exploring the principles of RF-resonant circuits for use in a wrap-around blanket seal that can be electronically interrogated.

Intrinsic-Surface Fingerprints

One well-developed Argonne unique identifier makes use of intrinsic-surface fingerprints.[6,7] The microscopic three-dimensional features of essentially any stable surface are unique. An optical microscope could be used for preliminary screening purposes, but the scanning electron microscope (SEM) is superior in detail and depth and resolution of three-dimensional objects.

There are two ways to use the SEM: directly and indirectly. For direct use, the surface itself (or a part containing the surface) is analyzed in the microscope. On the other hand, the indirect procedure takes advantage of a well-established metallurgical practice of making faithful plastic castings to bring to the SEM.

Direct SEM. The SEM is capable of providing detailed microscopic examination and identification of a surface, either the topography at micron-level detail, or the morphology by X-ray analysis. Much more characterization data—gigabytes per square centimeter—is available from the SEM than any other authentication tool. In addition to laboratory SEMs, commercial services are available. Argonne developed a prototype portable SEM from a purchased second-hand university unit. Portable SEMs have also been manufactured commercially.

Plastic-Castings of Surfaces. Faithful plastic castings, analogous to human fingerprints, can be made of surfaces. These copies can be stored for future recall and processing at an SEM. Unique three-dimensional detail of microscopic irregularities are captured by surface replication. The process of making the plastic castings and storing the fingerprints is relatively simple and inexpensive, being fully satisfied in the field by materials that could even be purchased at a hardware store—cellulose acetate and acetone.

The user procedure would be to bring the casting to an SEM Laboratory for examination. Argonne has an SEM facility developed by DOE and dedicated to this purpose. Although commercial SEM services are also available, Argonne has prepared special software and algorithms to carry out the image comparisons.[8,9]

Castings of Welds. Filling a need still not satisfied are castings that can be made of welds used to seal containers. Even though containers might be tagged and their lid sealed, the possibility of cutting through a weld seam and rewelding is a weak aspect of some high-security seals. Special plastic castings could made of the deeper surfaces characteristic of welds.

Both the direct and the indirect methods of fingerprinting are fully developed and ready for small-scale use. Studies have been carried out on corrosion protection and perceived weaknessess. A national laboratory funded by DOE was unable to produce deceptive intrinsic-surface counterfeits.

Russian laboratories have indicated keen interest and have demonstrated equipment and analytical capabilities for intrinsic-surface fingerprinting. Both of their nuclear-weapons laboratories, Arzamas-16 and Chelyabinsk-70, submitted collaborative proposals to the International Science and Technology Center.

In a modern environment, one of the most intriguing possible applications would be for covert (or overt) identification of manufactured objects or containers that are subject to domestic or international shipment. Because the plastic-casting fingerprint technique leaves no indication that the object has been "tagged," perpetrators of illegal use of controlled objects will not know that the object is identifiable.

Radiation Dosimetric Tag

To meet earlier arms-control expectations of a TID that would passively measure long-duration radiation, a dosimetric tag was being developed. The purpose was to verify that a radiation source higher than ambient background was not introduced, or that the radiation source in the container was not changed. For example, cumulative radiation dose measurements could have been used to ensure that conventional warheads were not replaced by nuclear warheads on cruise missiles. Although progress was made, development was not completed.

Transcom Satellite-Linked Seals

Shipments of highly sensitive items, such as special nuclear materials, might require near-real-time tracking. By combining electronic-identification devices with a commercial satellite system, special nuclear materials under transport can be monitored.

An electronic tag developed by Livermore, attached to valuable or sensitive shipments (such as trains carrying nuclear warheads or missiles), will have security-status data transmitted to commercial satellites. Argonne is developing the interface for real-time tracking.

Time-Signature Seal

A new concept for a time-stamped seal has been devised.[10] The time-signature seal could allow visual and/or electronic indication of the moment when the seal is applied and the time when the seal is legitimately or illegitimately opened.

Based on commercial digital-watch technology, the seal would display closure time. The year/month/day/hour/second/millisecond time of sealing qualifies as a random unique identifier. An option is to provide a second internal clock, which—when the seal is broken—would be disabled and capture the time of reopening.

The time-signature seal is expected to be inexpensive and simple to use. Additional tamper-resistant barriers could be incorporated in the design. To date, no hardware development work has been conducted on this concept.

Inert Gas Tagging

For tagging sealed containers, distinctive inert gas fills could be useful. Experience had been gained by sealing fuel pins in nuclear reactors: Leakage of the inert gas was detected by monitoring instrumentation.

This method could be applied to sealed containers for nuclear-warhead pits resulting from dismantlement. The pit containers could be filled with selected mixtures of Xe, Kr, and Ar (having varying isotopics), such that localization of leakage or unauthorized breaching could be achieved.

The entire facility could itself be maintained under an inert atmosphere, the gas constantly being monitored for container leakage—thus making it extremely difficult for undetected entry or opening of a container. Inert-gas tagging would be primarily useful for new or resealed containers of high-valued objects, especially where it is desirable to store the object under stable conditions.

Detection of tagged gasses would constitute indication of a container (or facility) breach. Measurement of isotopic ratios could be used to localize the leak within a facility.

SUMMARY

The novel techniques described above have renewed potential in the post-Cold-War security environment, such as nuclear safeguards and export controls. Some of these tamper-resistant unique identifiers are especially tolerant to adverse conditions. Others could fill a technology gap for flexible tamper-indicating "blankets" to wrap around irregular objects, including valves, flanges, and munitions.

The intrinsic-surface technique is especially interesting as a low-cost and immediately available tagging method. Since nuclear security can be improved in the new states of the FSU, simplicity and low-cost have attracted the interest of Russian weapons laboratories. Being particularly useful for covert identification gives the fingerprinting technique universal potential.

Inert gas tagging offers potential leak or breach detection and localization in storage facilities for nuclear pits.

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